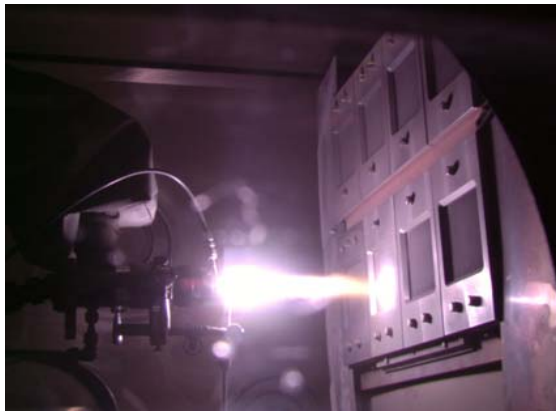


Anwendung in-situ diagnostischer Methoden für die Untersuchung oxidkeramischer Brennstoffzellen

G. Schiller, H. Ax, W. Bessler, C. Christenn, Z. Ilhan, P. Szabo, C. Willich

Deutsches Zentrum für Luft- und Raumfahrt, Institut für Technische Thermodynamik
Pfaffenwaldring 38-40, D-70569 Stuttgart

Development of Metal Supported Cells (MSC)



Characterization of Short Stacks and Stacks (ASC, MSC)

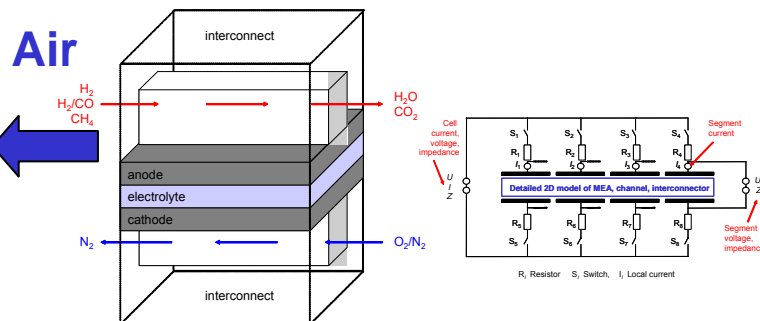
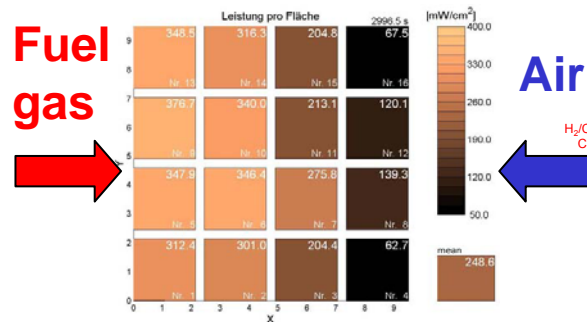


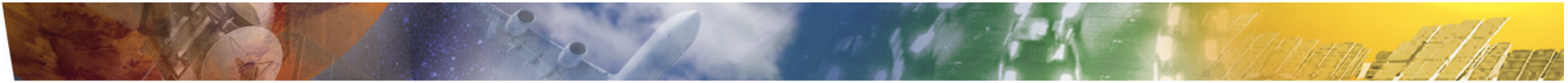
SOFC Activities at DLR

SOFC Modeling

System Technology

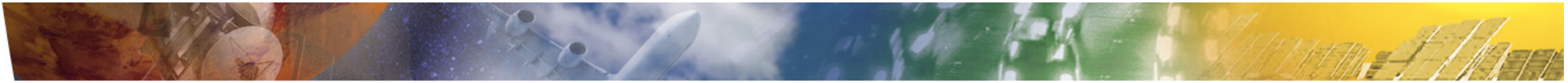
SOFC Diagnostics





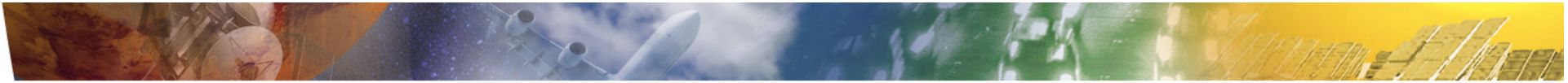
„Sophisticated“ (non-traditional) In-situ Diagnostics

- Electrochemical impedance spectroscopy on stacks
- Spatially resolved measuring techniques for current, voltage, temperature and gas composition
- Optical imaging
- Optical spectroscopy
- Acoustic emission detection
- X-ray tomography



Outline

- Introduction
- Experimental setup for spatially resolved measurements
- Exemplary results of spatially resolved measurements:
 - MSC cell
 - ASC cell with high fuel utilization
 - ASC cell with reformat as fuel gas
- Raman spectroscopy
- Conclusion



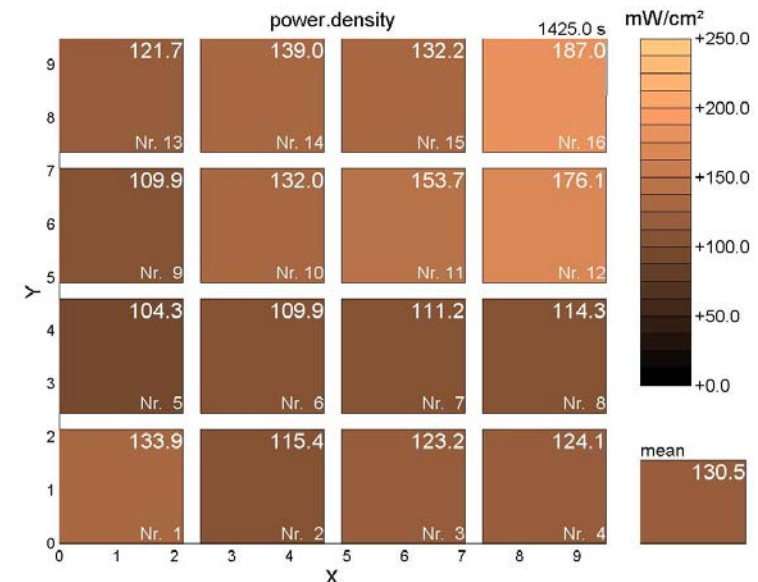
Motivation

Problems in planar cell technology:

- Strong local variation of gas composition, temperature, and current density
- Distribution of electrical and chemical potential dependent on local concentrations

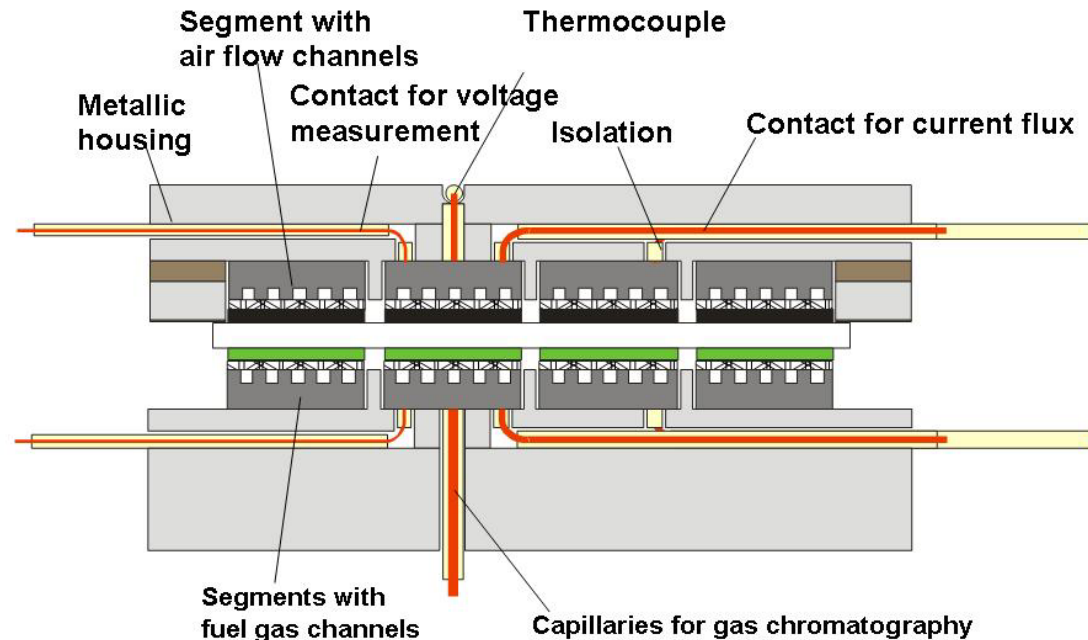
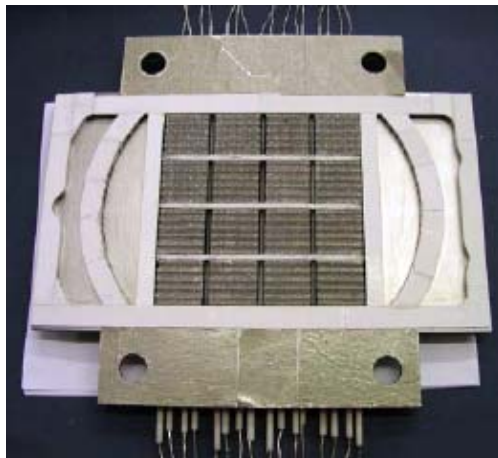
This may lead to:

- Reduced efficiency
- Thermo mechanical stress
- Degradation of electrodes

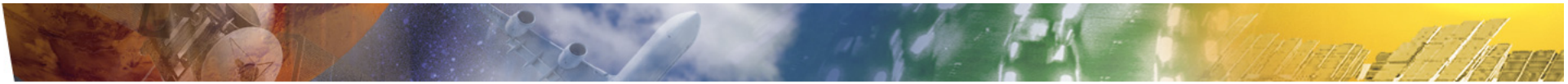


Effects are difficult to understand due to the strong interdependence of gas composition, electrochemical performance and temperature

Measurement Setup for Segmented Cells



- 16 galvanically isolated segments
- Local and global i-V characteristics
- Local and global impedance measurements
- Local temperature measurements
- Local fuel concentrations
- Flexible design: substrate-, anode-, and electrolyte-supported cells
- Co- and counter-flow



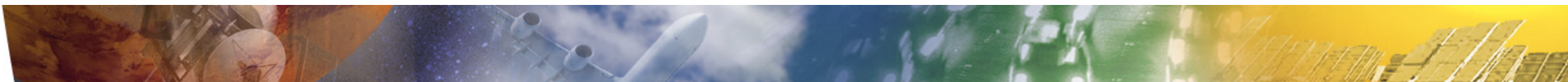
Segmented Cells

- Anode supported cells:
Segmented cathode
(H.C.Starck/InDEC)

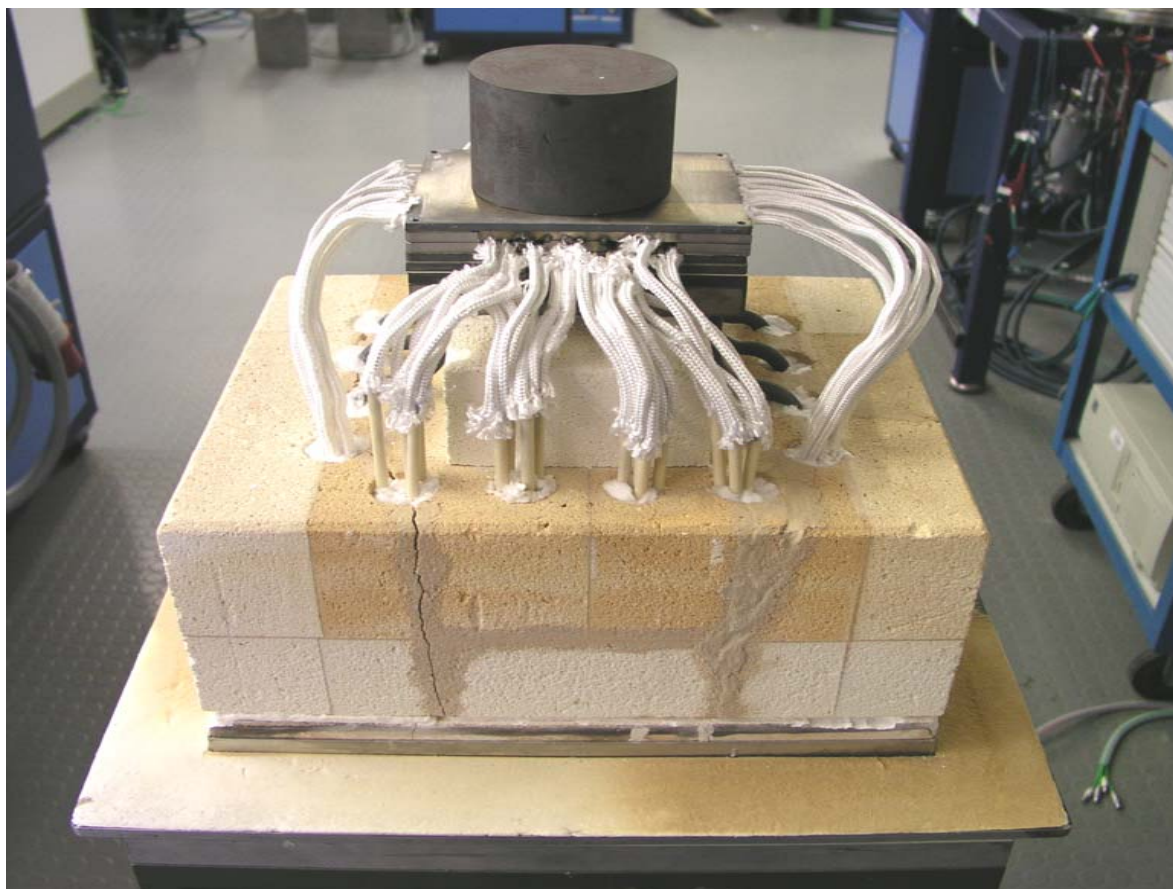


- Electrolyte supported cells:
Segmented cathode and
anode



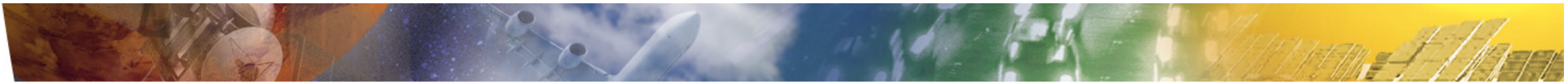


Test Rig



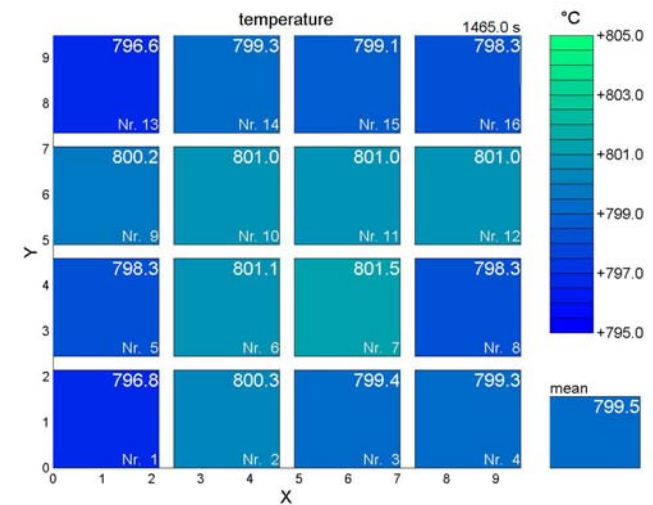
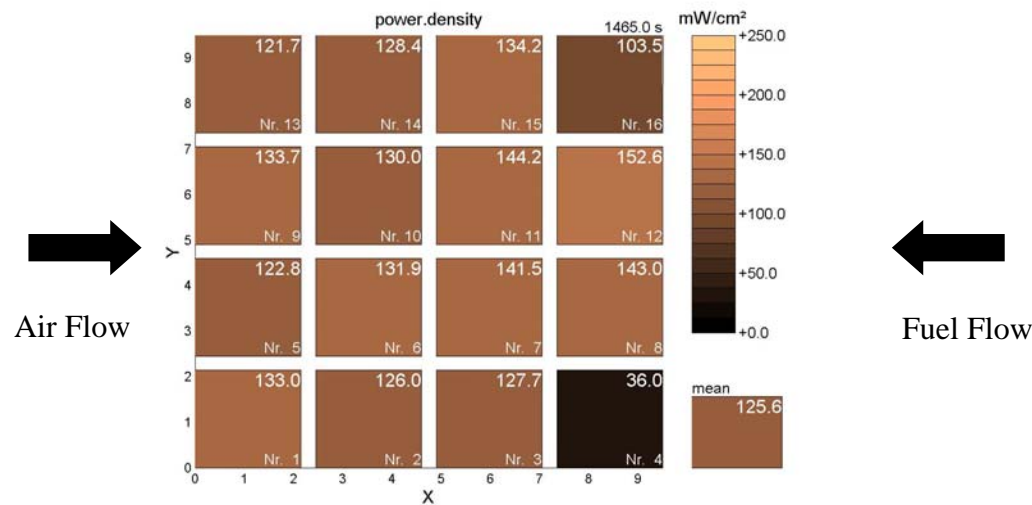
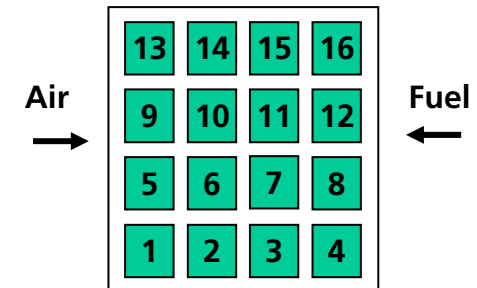
Deutsches Zentrum
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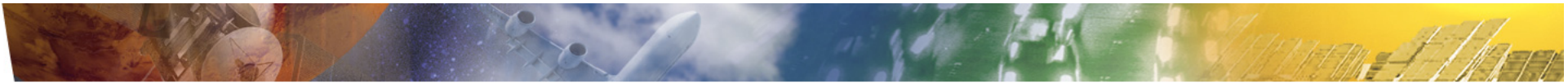
4. Sächsischer Brennstoffzellentag, Leipzig, 10. November 2011



Power Density and Temperature Distribution of a Plasma Sprayed Cell

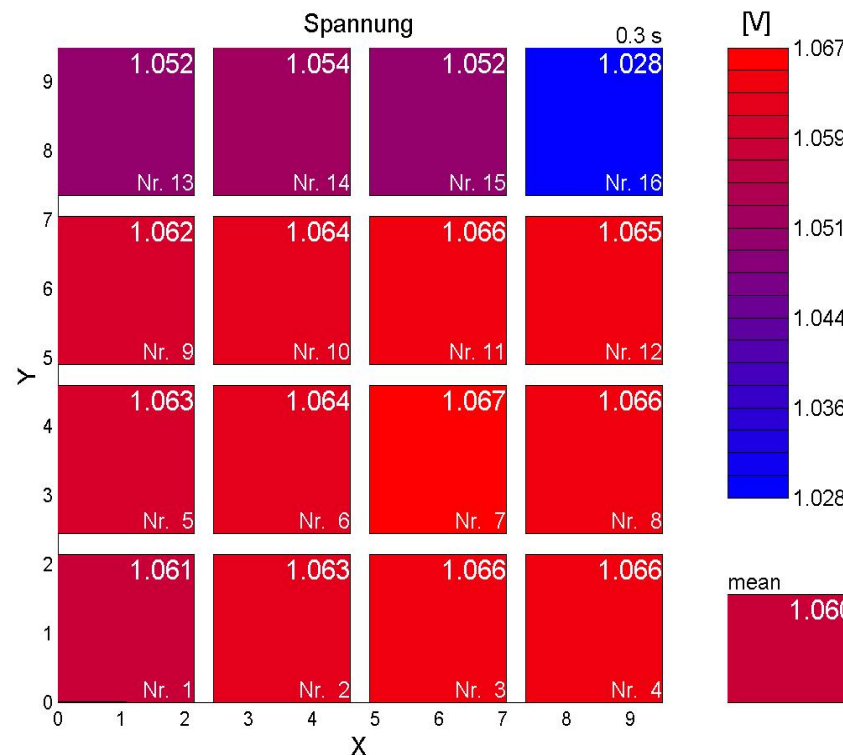
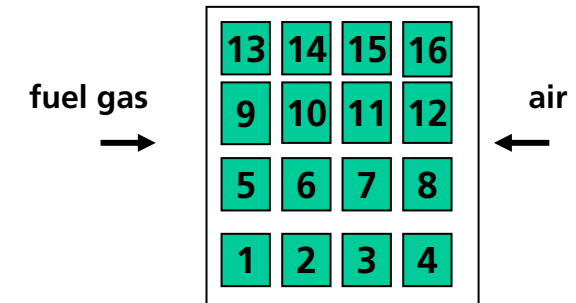
- P und T distribution at standard gas flow rates: 12,5/12,5//80 smlpm/cm²
H₂/N₂//Air, 800°C, 0.7 V,





OCV Voltage Measurement for Determination of Humidity

- Voltage distribution at standard flow rates:
- 50% H₂, 50% N₂ + 3% H₂O, 0.08 SlpM/cm² air

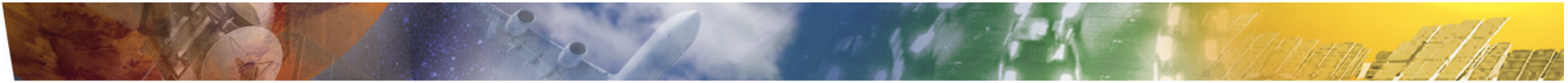


Nernst equation:

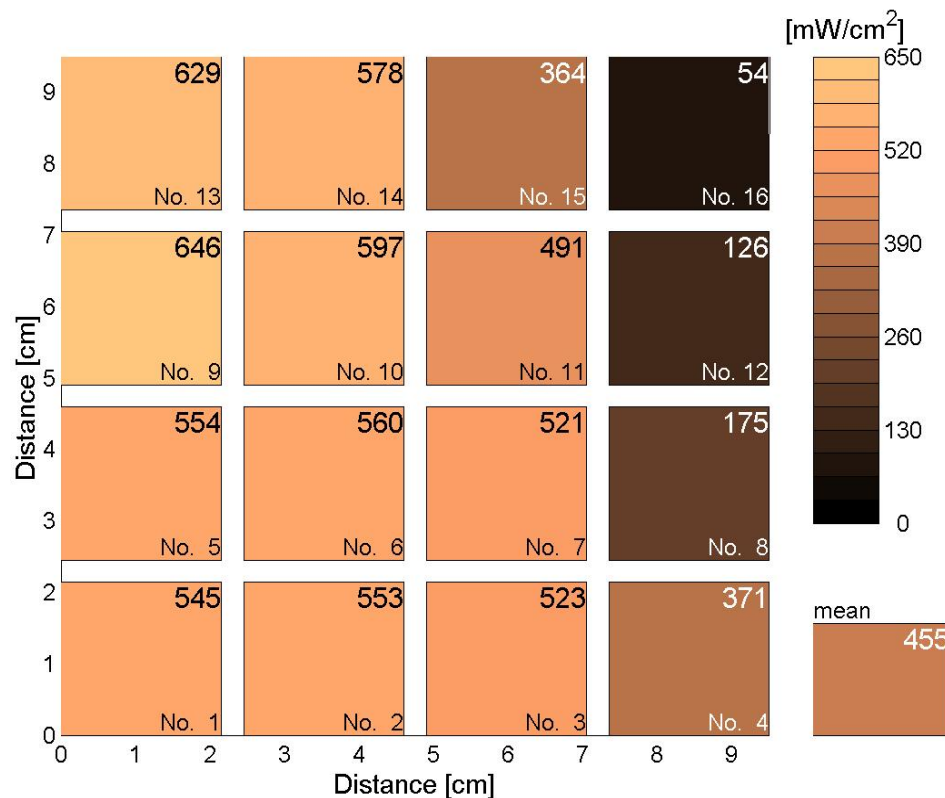
$$U_{rev} = U_{rev}^0 - \frac{RT}{zF} \ln \left(\frac{p_{H_2O}}{\sqrt{p_{O_2} p_{H_2}}} \right)$$

Produced water:

S4: 0.61%, S8: 0.72%,
S12: 0.78%, S16: 3.30%



Power Density Distribution under Conditions of High Fuel Utilization



Counter-flow

Anode: 33% H₂, 1% H₂O,
66% N₂

Cathode: air

T = 800 °C

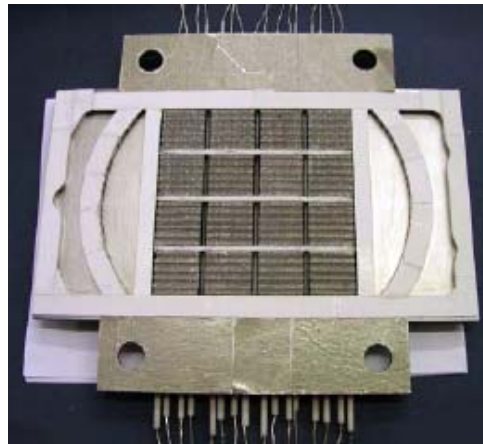
Cell voltage: 0.59 V

F_u = 80%

Lit.: Fuel Cells, 10 (3), 411-418 (2010)

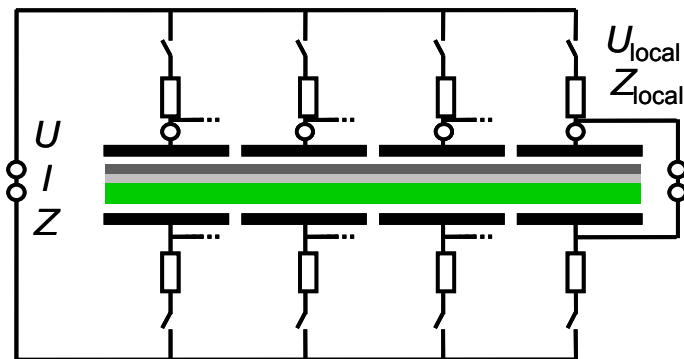
Assessment of Local Performance with Segmented SOFCs

Experiment

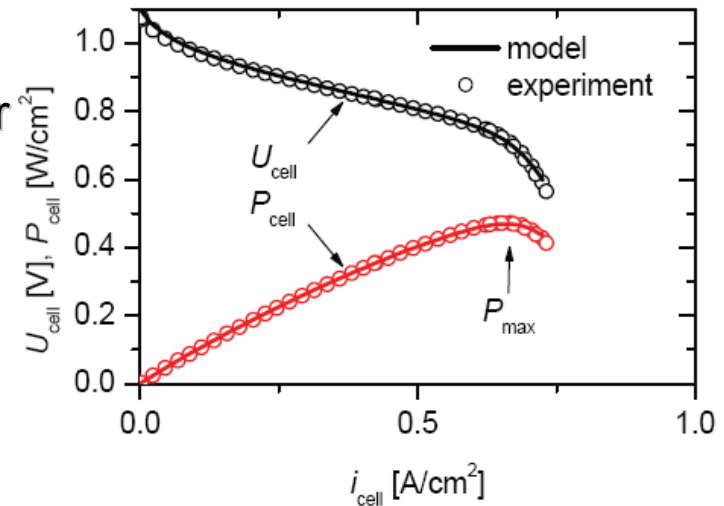


16
segments

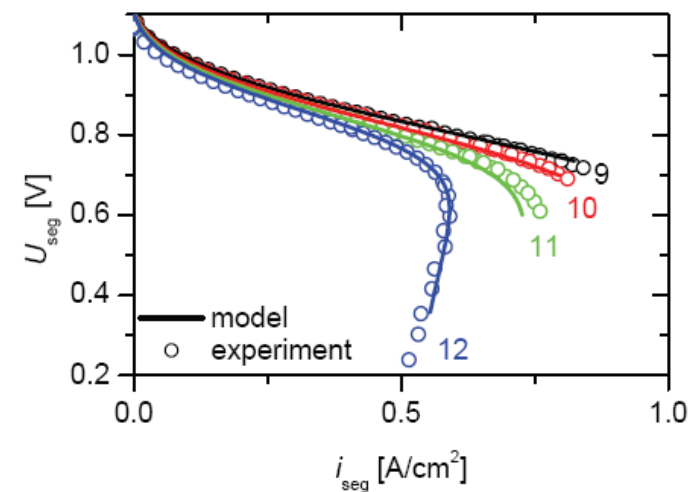
Model



Global behavior



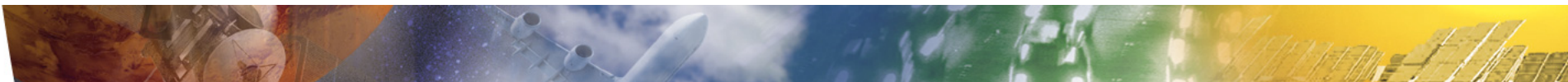
Local behavior



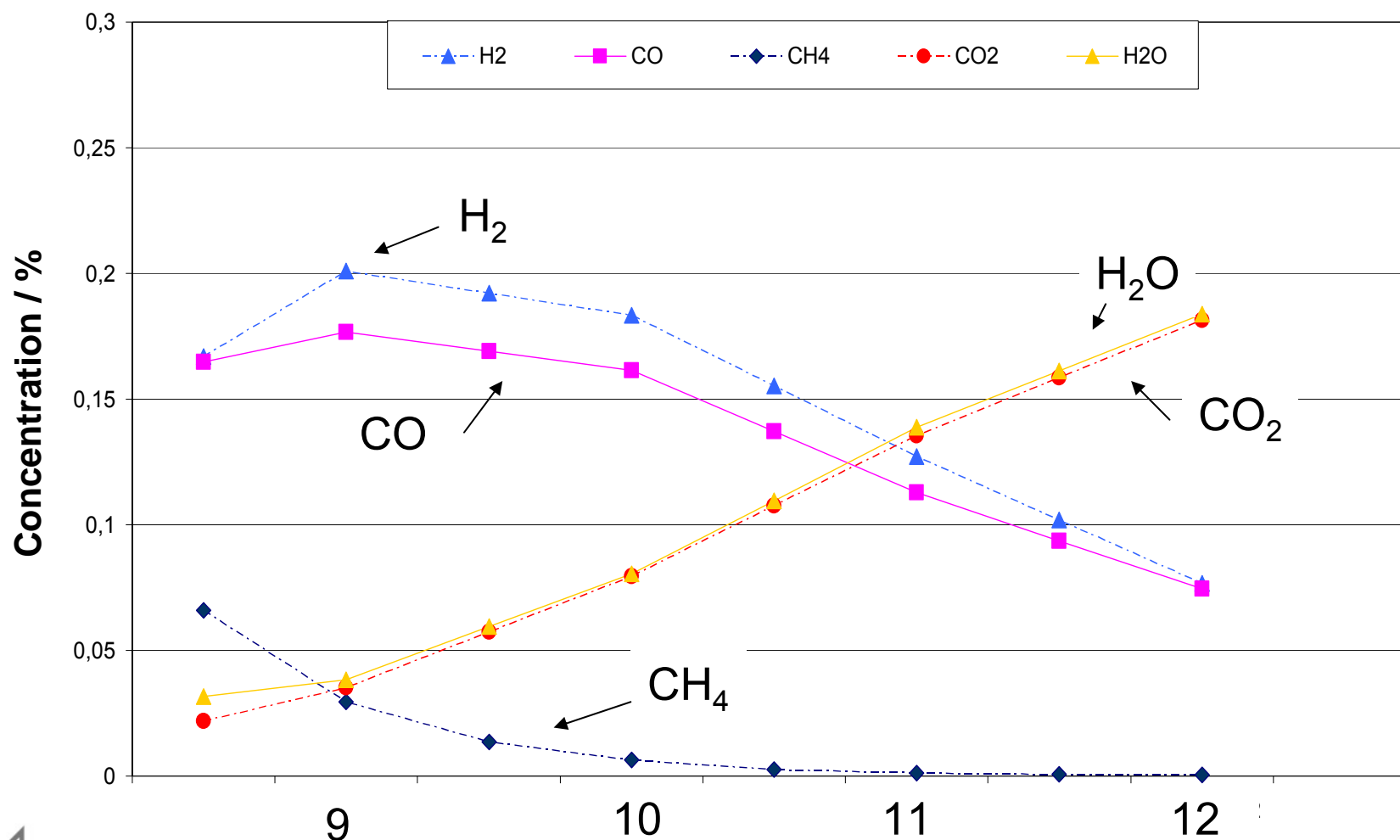
Cell can be locally in critical conditions!

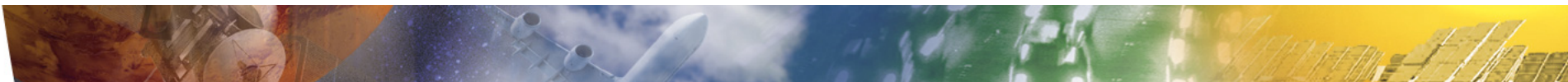


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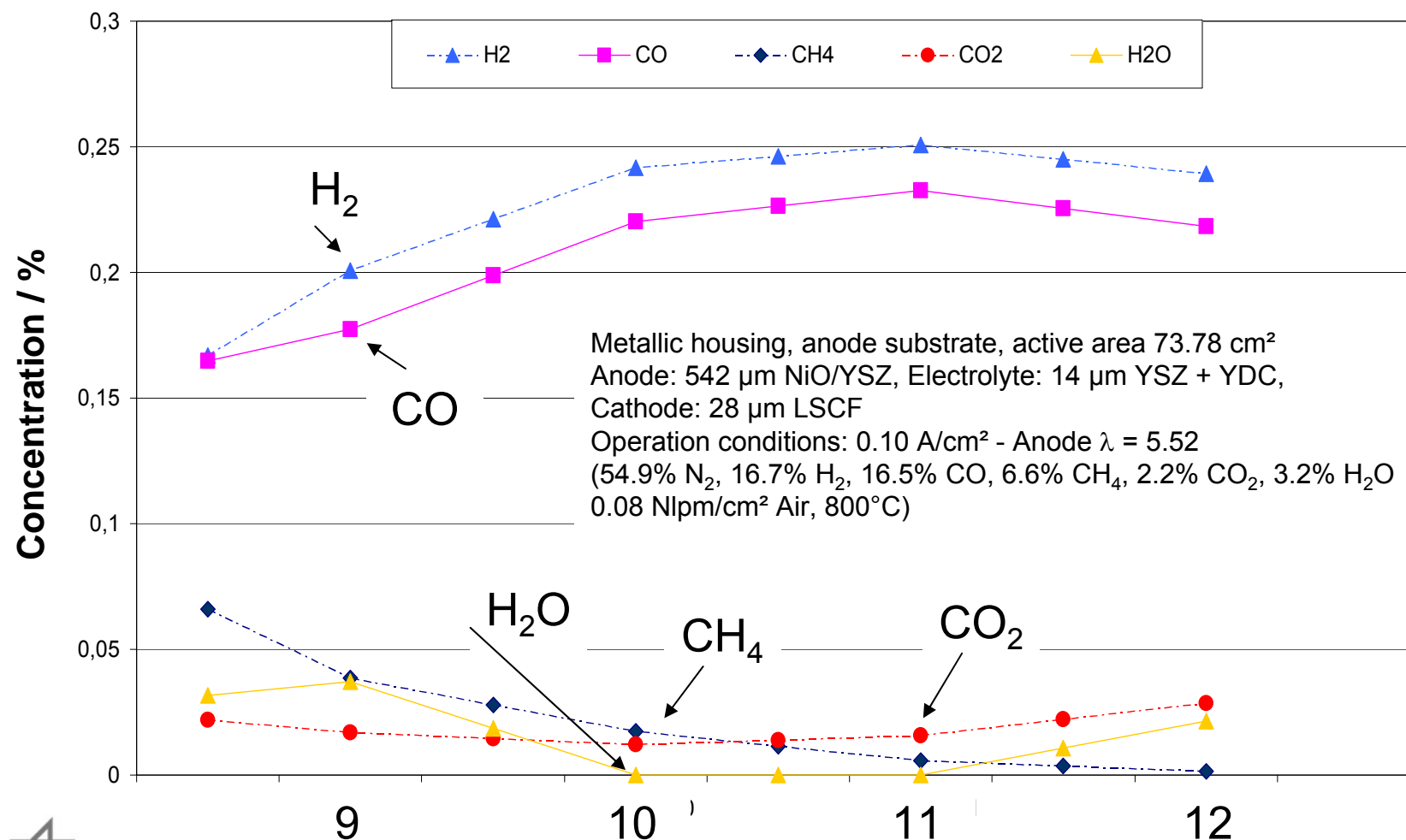


Alteration of the Gas Composition at 435 mA/cm²

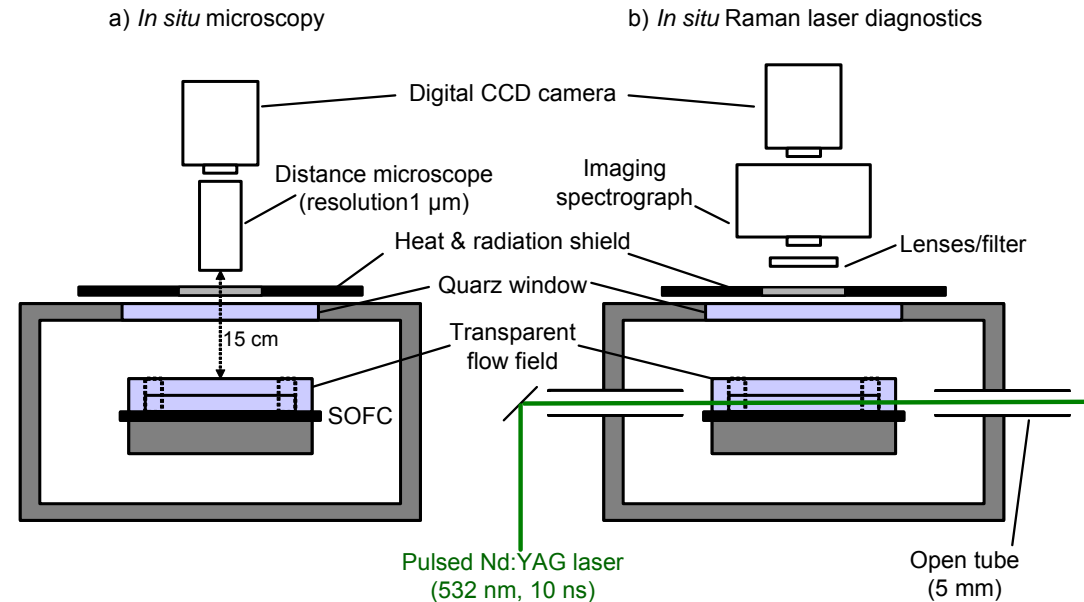




Alteration of the Gas Composition at 100 mA/cm²



Potential for Optical Spectroscopies



Raman spectroscopy

Laser Doppler Anemometry (LDA)

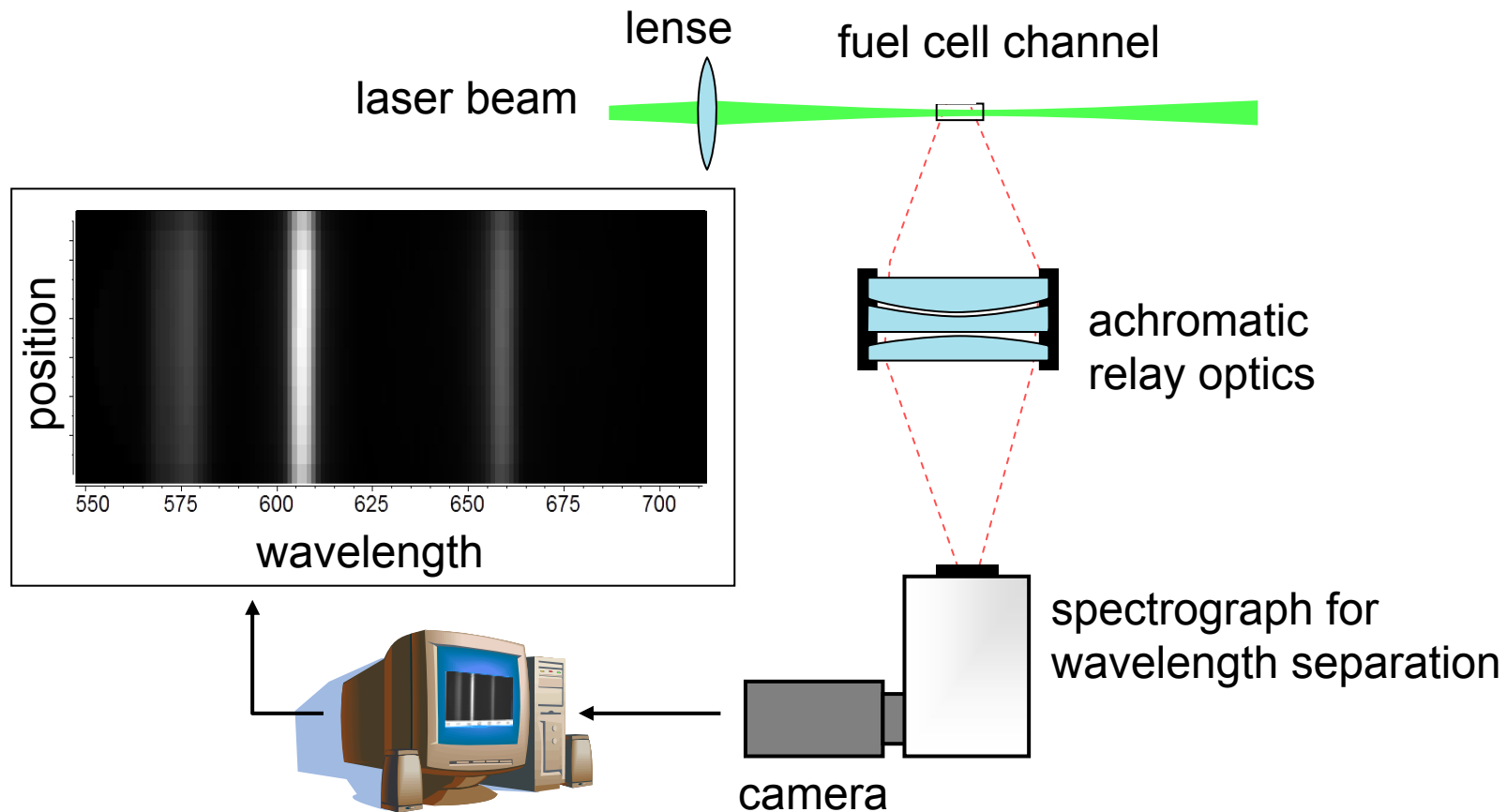
Particle Image Velocimetry (PIV)

Fast-Fourier Infrared (FTIR)

Coherent Anti-Stokes Raman Spectroscopy (CARS)

Electronic Speckle Pattern Interferometry (ESPI)

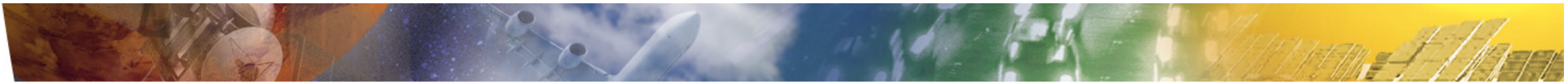
1D Laser Raman Scattering: Experimental Arrangement



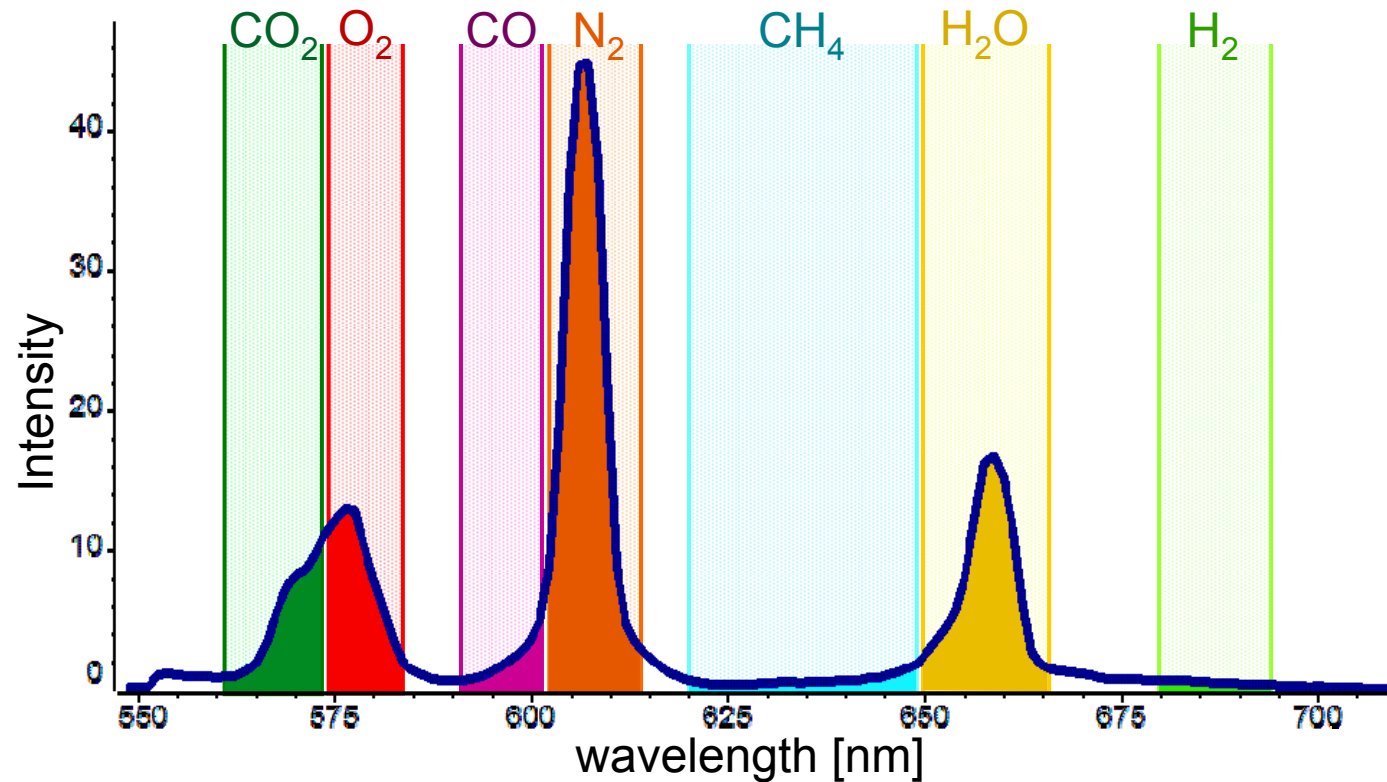
Simultaneous detection of CH_4 , O_2 , N_2 , CO , H_2 , CO_2 , H_2O



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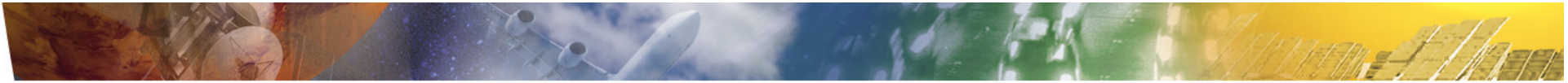


Raman Spectrum from Flame



Raman bands are partly overlapped (cross talk)





Setup for 1D-Raman Spectroscopy

3 double pulse Nd:YAG PIV 400 laser systems

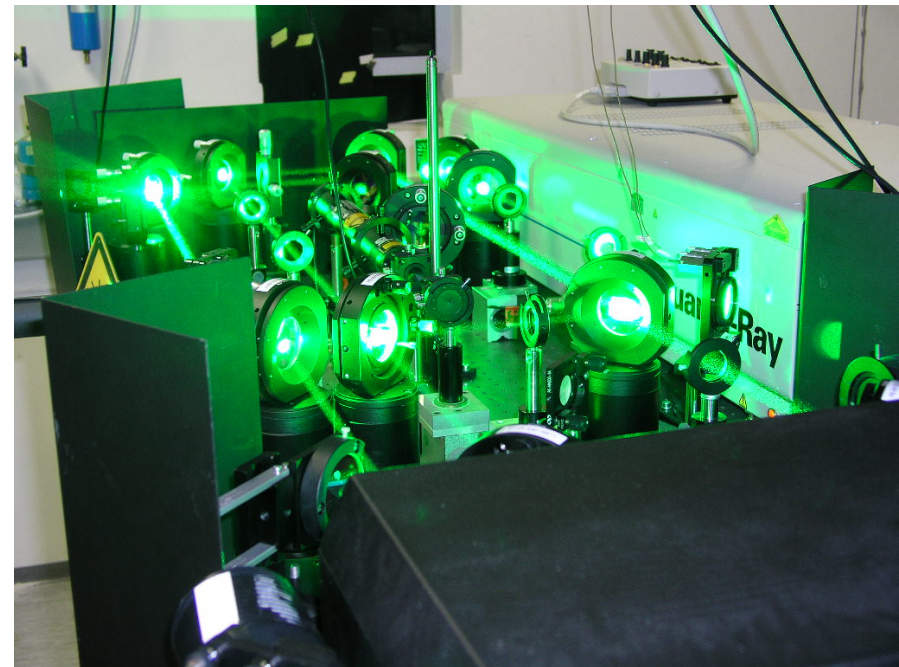
$\lambda = 532 \text{ nm}$

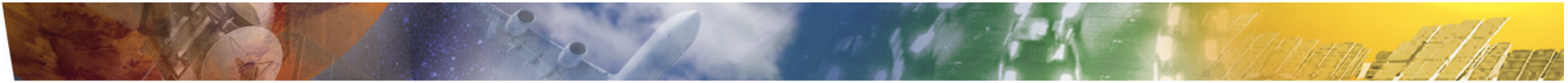
Repetition rate: 10 Hz

Single pulse: $E \leq 350 \text{ mJ} / \sim 7 \text{ ns}$

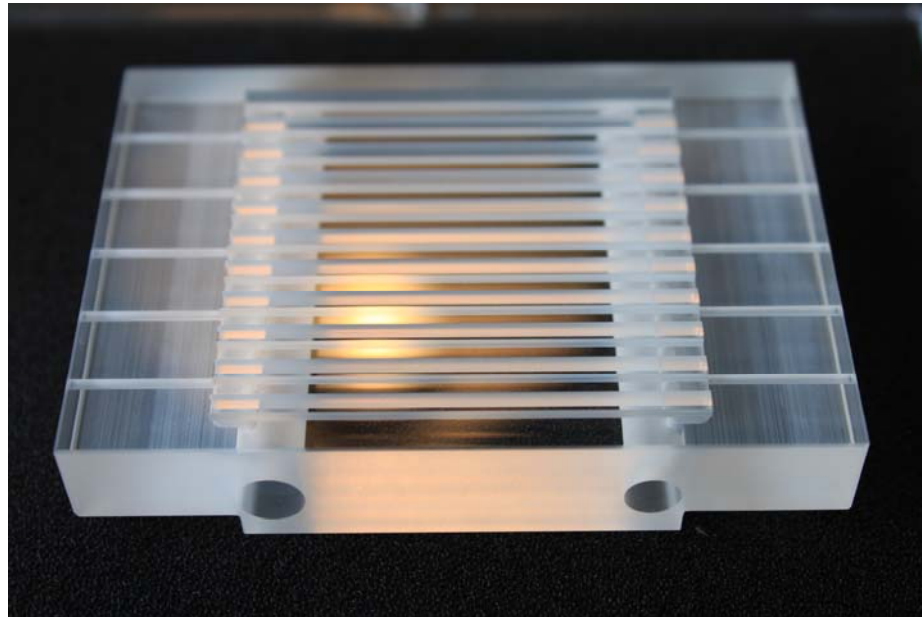
Pulse energy: 6 x 300 mJ

Pulse length: $\sim 380 \text{ ns}$
(temporal resolution)

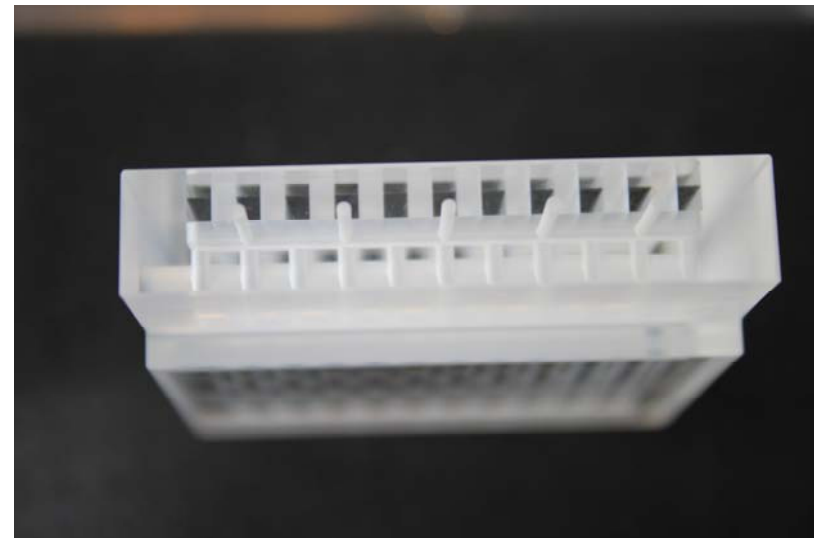




Transparent Flowfield for SOFC



Top view

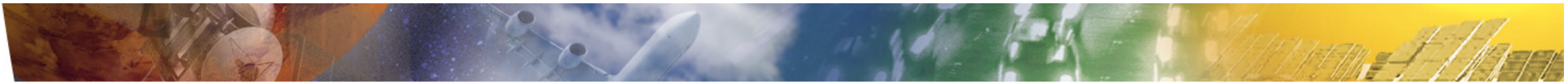


Side view

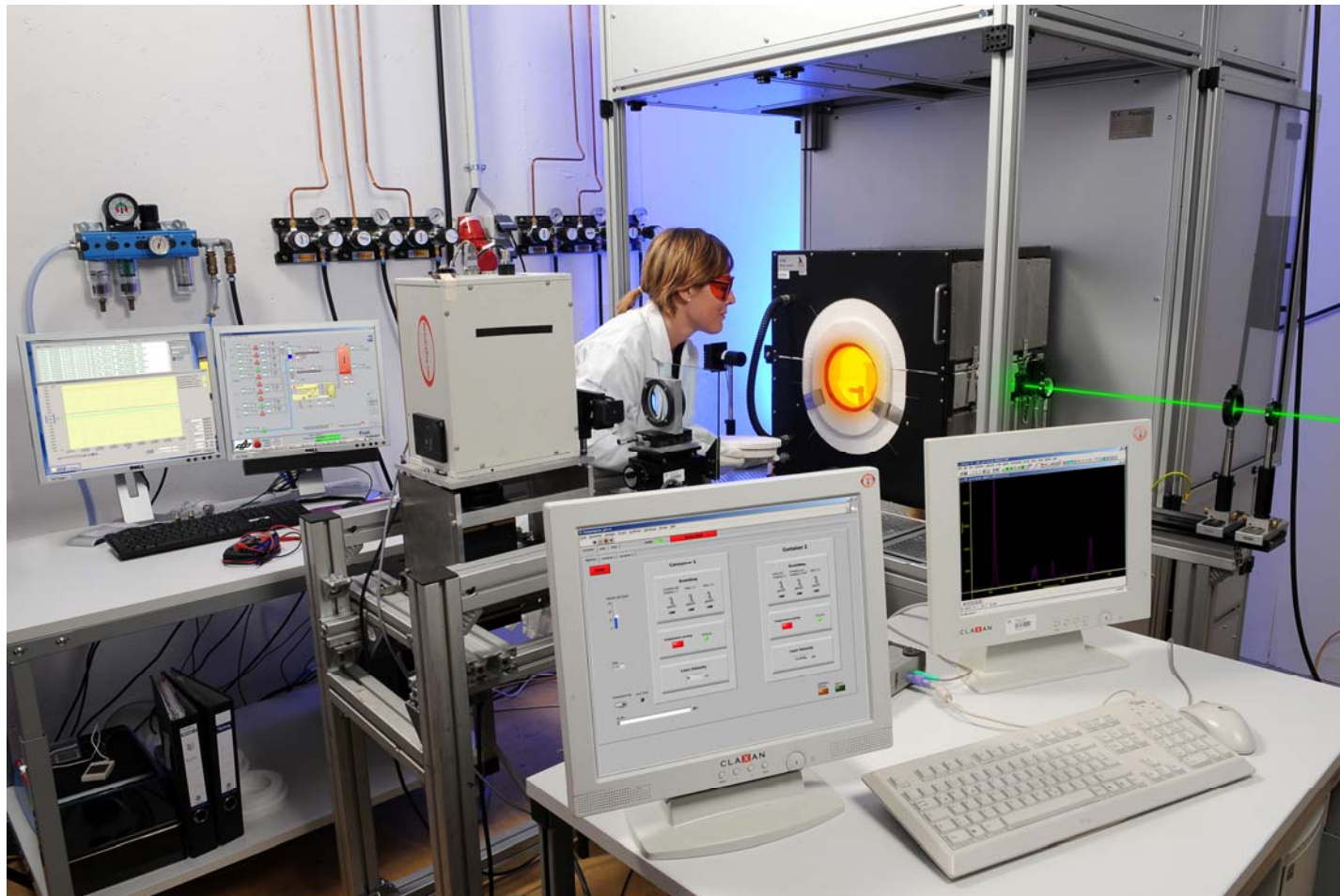


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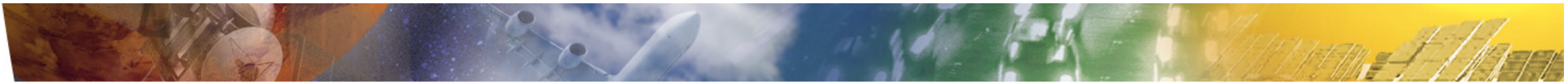


Experimental Setup for Raman Spectroscopy Measurements

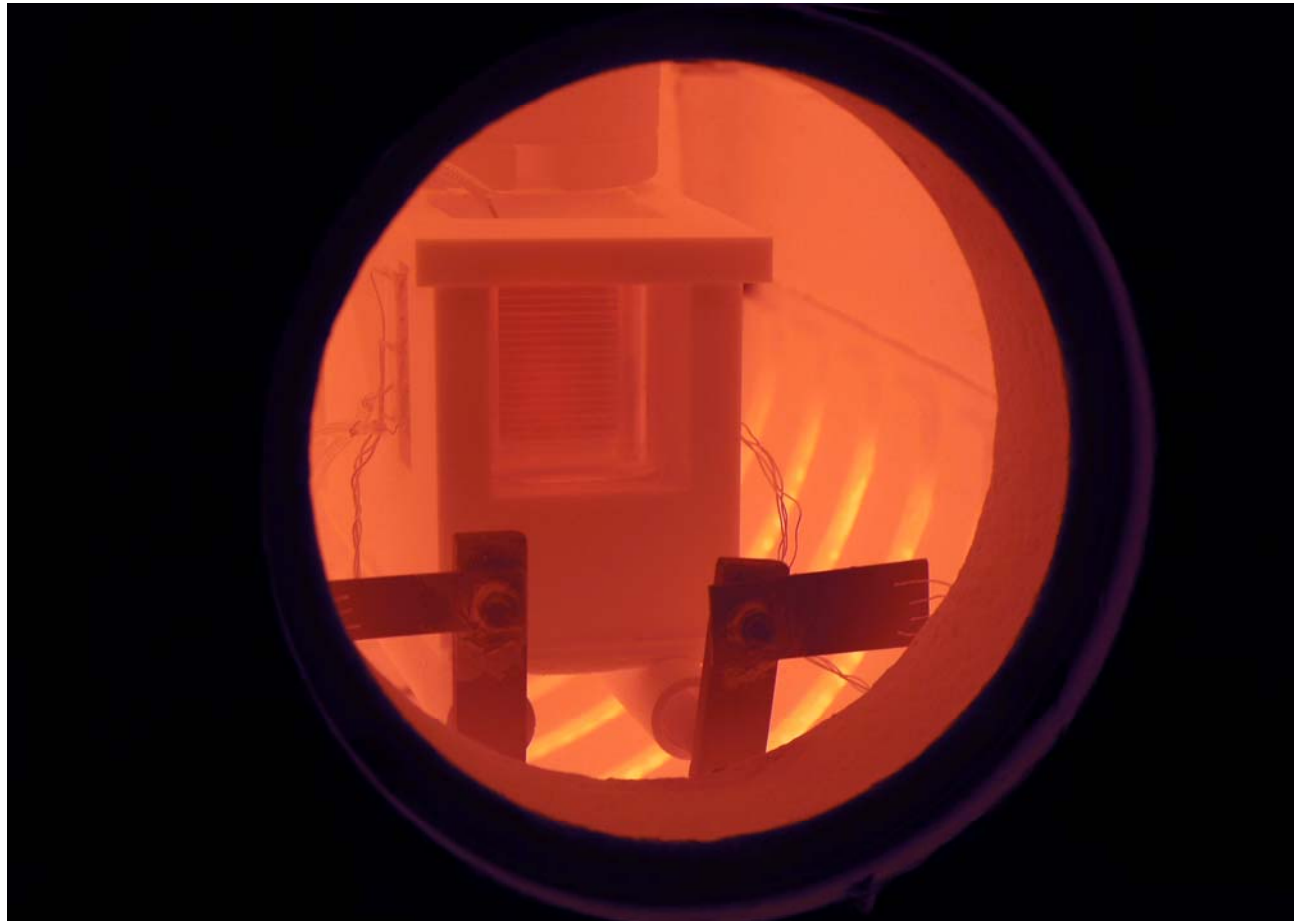


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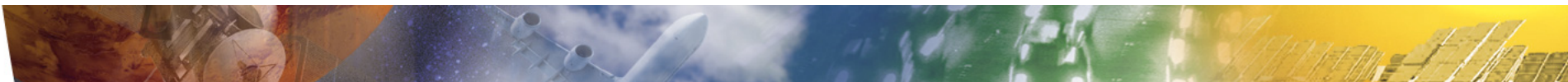


Cell Housing with Transparent Flowfield in Hot Furnace

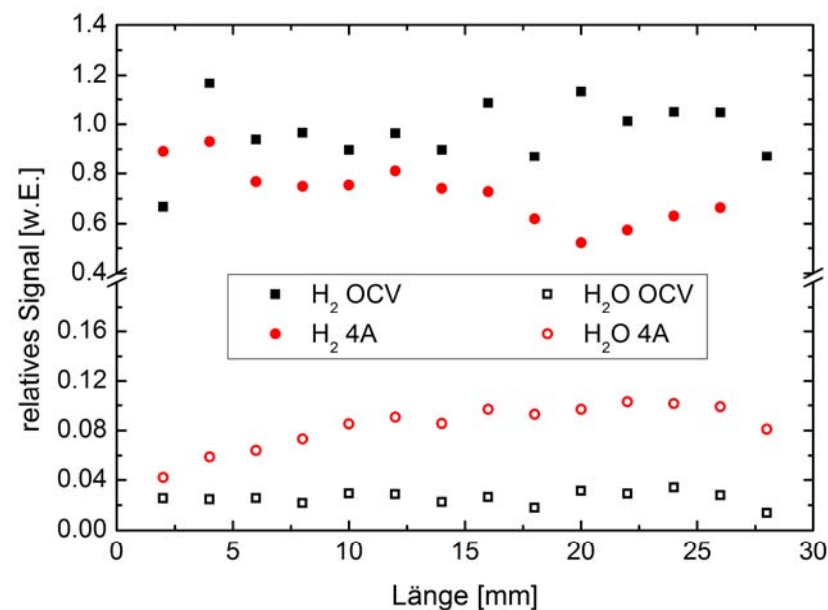
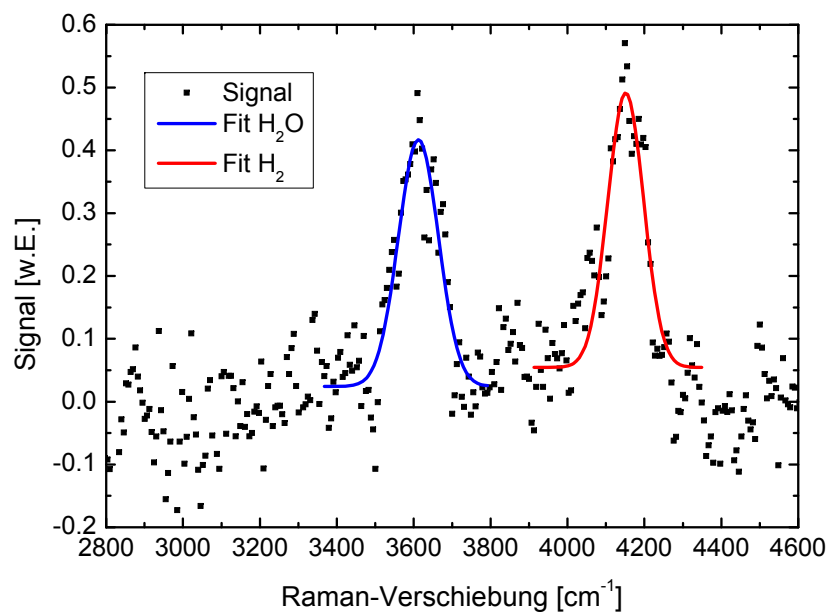


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Raman Spectra of H₂ and H₂O Concentrations Along the Flow Channel

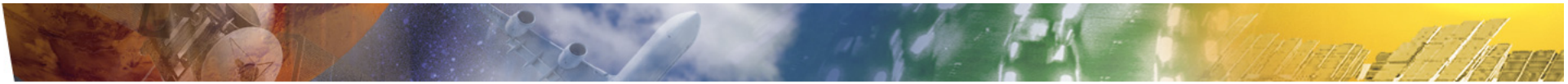


H₂ + 3% H₂O; 0,112 NL/min H₂, 1,06 NL/min air, 850 °C

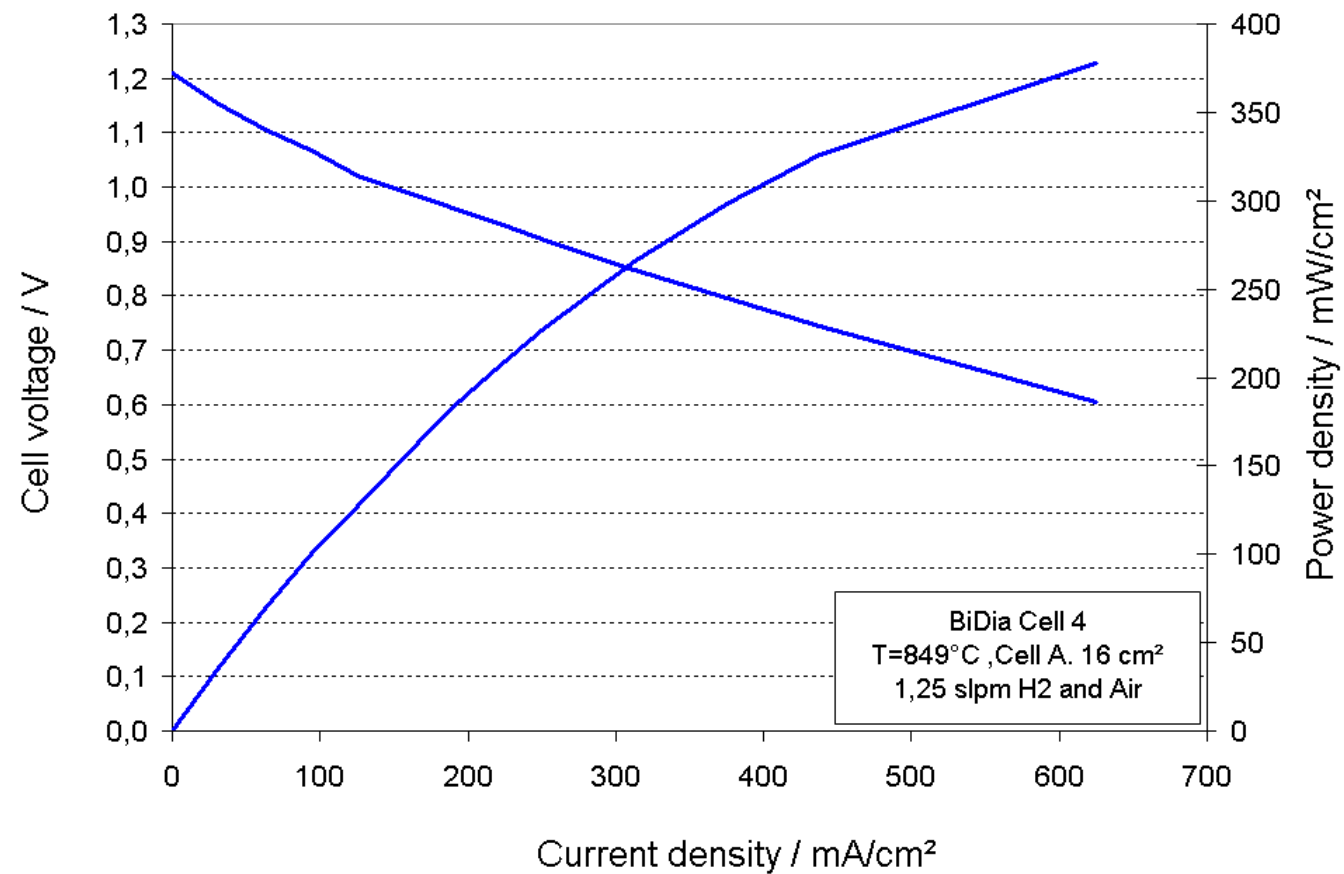


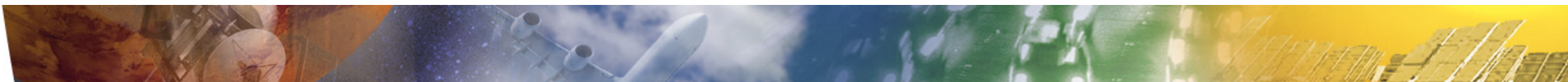
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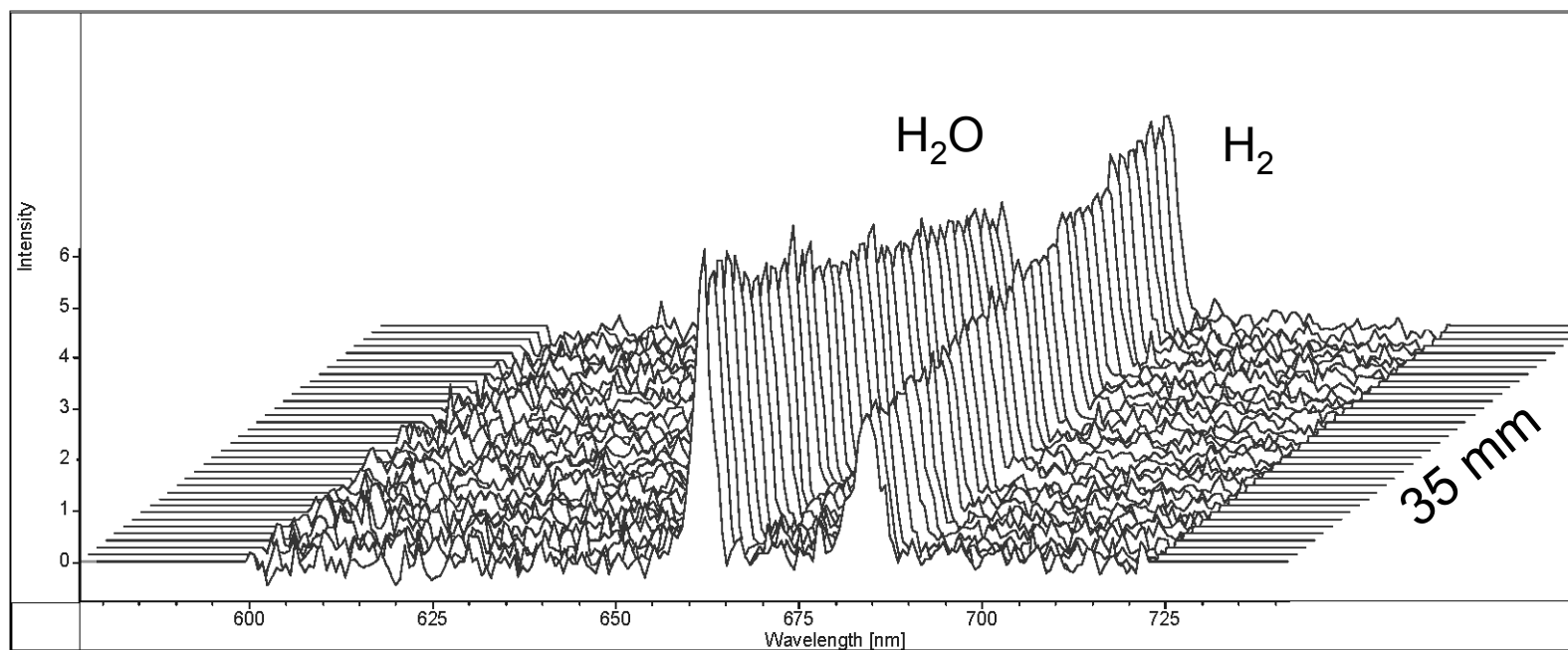


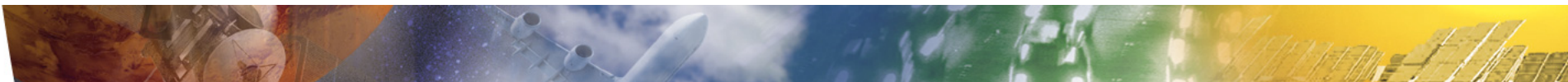
IV Characteristics of ESC Cell



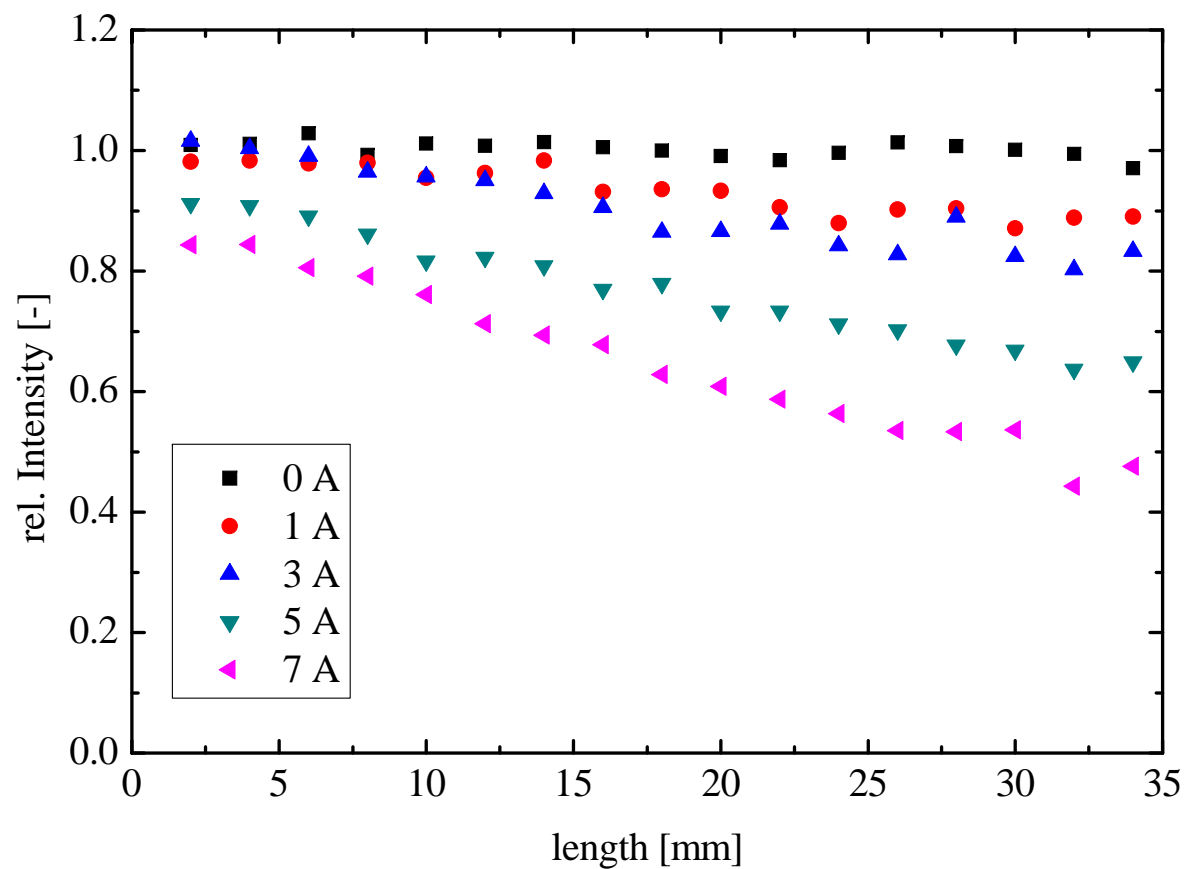


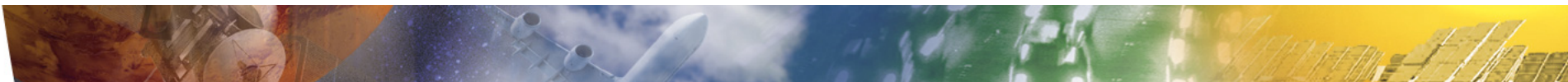
Raman Spectra of an ESC Cell Operated at 5 A



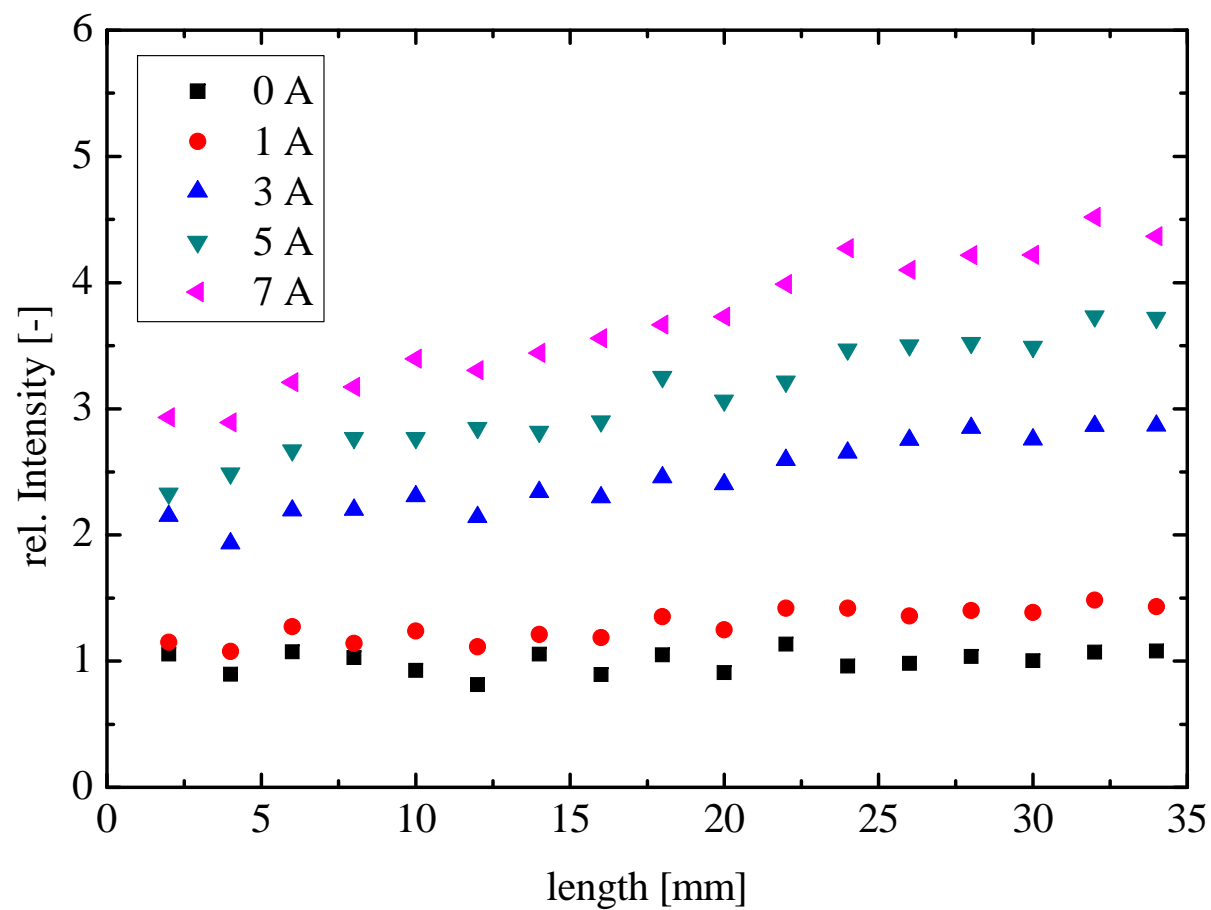


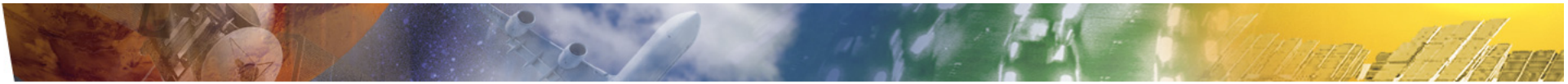
Raman Signals of H_2 as a Function of Distance Along the Flow Channel



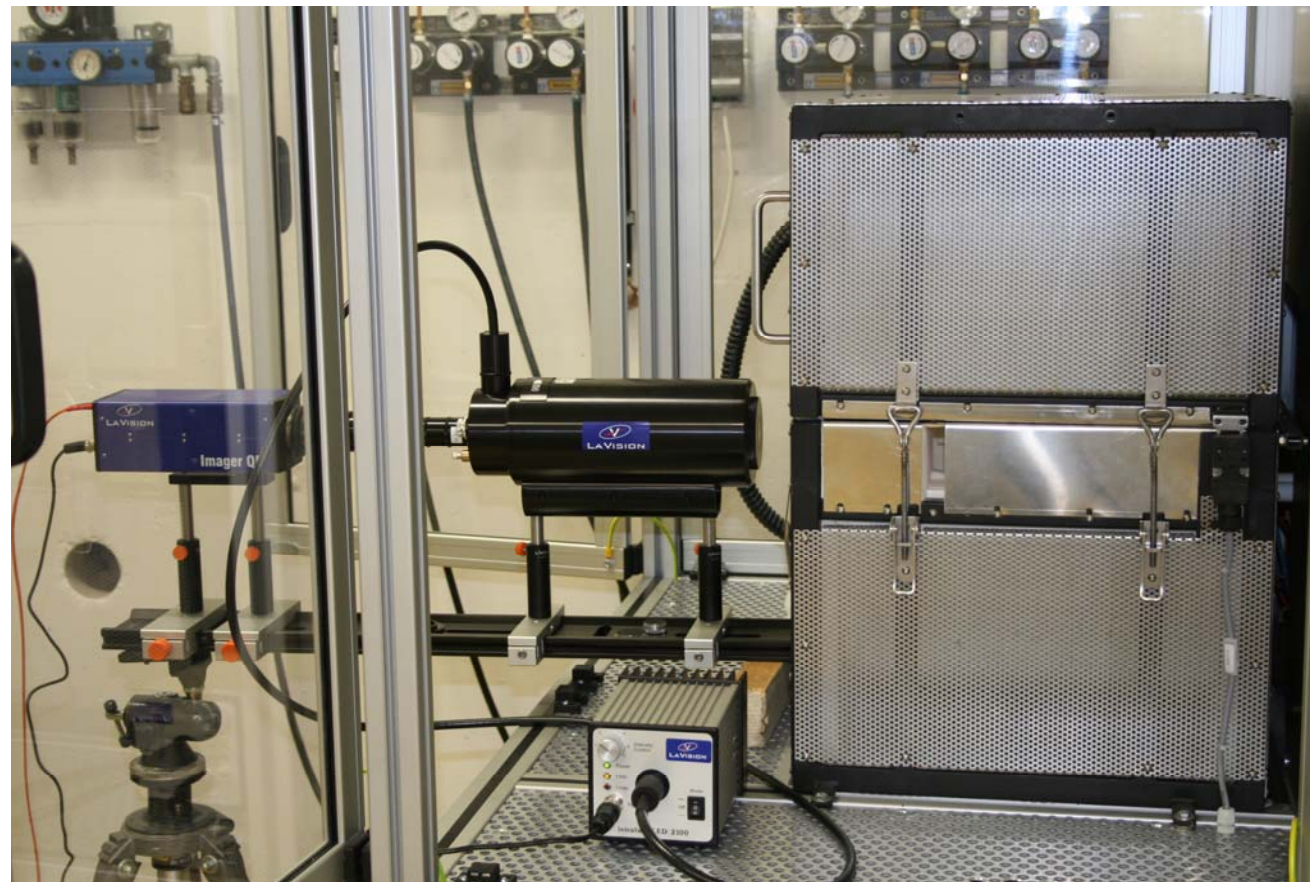


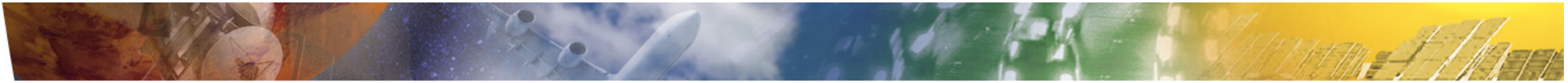
Raman Signals of H₂O as a Function of Distance Along the Flow Channel





Setup for In-Situ Optical Microscopy





Conclusion

- In-situ diagnostic techniques allow for a largely extended insight into fuel cell processes (fundamental understanding, optimization of flow field)
- The potential of spatially resolved diagnostics was demonstrated with some exemplary results
- The obtained data can be used for modeling and simulation for identification of critical operating conditions
- Strong gradients of gas concentrations and current density particularly at operation with high fuel utilization may result in locally critical operating behavior
- Qualitative results of Laser Raman Spectroscopy measurements have been shown, quantitative measurements are in progress.